DRILLING OF GLASS FIBER REINFORCED POLYMER (GFRP) COMPOSITES: PARAMETRIC APPRAISAL AND MULTI RESPONSE OPTIMIZATION

Thesis submitted in fulfillment of the requirements for the award of the Degree of

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In

Production Engineering

By

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Certificate of Approval

This is to certify that the thesis entitled ***Drilling of glass fiber reinforced polymer (GFRP) composites: Parametric appraisal and multi response optimization*** submitted by ***Mr. Abhishek Singh*** has been carried out under my supervision in the fulfilment of the requirements for the Degree of ***Master of Technology*** in ***Production Engineering*** at National Institute of Technology, Rourkela, and this work has not been submitted elsewhere before for any other academic degree/diploma.

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Abhishek Singh

Abstract

In today's scenario, composite like Glass Fiber Reinforced Polymer (GFRP) is a standout amongst the most alluring and profitable material among all the designing materials. The reason for using these composite laminates is their superior properties and their influential application in aerospace industries, aircraft structural components, and others. The present learning about machining of GFRP composites is in a moving stage for its ideal usage in different fields of uses in the monetary perspective. Hence, the hypothetical mechanics have ended up overwhelming in this field to attain to completely mechanized substantial scale assembling cycles. Composites fluctuate in their machining direct as a consequence of their mechanical and physical properties that basically depend on upon the kind of fiber, content of fiber, alignment of fiber, and inconsistency in the matrix material.

The very common operation for the assembly of components made up of GFRP is using rivets and joints. To join components by rivets and joints the basic requirements is good quality holes, for which drilling operation is performed. Drilling of GFRP by the conventional methods is a complicated machining process, to achieve good quality hole, as glass fibers are used in the material. Likewise, composite overlays are viewed as difficult to machine materials. Drilling process is highly depended on the cutting parameters (i.e. Feed, Speed, and Drill Diameter), tool geometry, instrument and workpiece material, delamination along with torque and thrust force. Optimization is done to get the nominal measures for all parameters.

The drilling parameters like spindle speed and feed rate are improved by considering various performance qualities, such as surface roughness of the workpiece, delamination occurred while drill along with thrust force. Understanding the machining behavior of the work-piece results in

least waste and defects. To evaluate thrust force and torque, motionless and active analysis of the work-piece is done. Multi-response optimization is termed as a process of opting the best suitable alternative among all the options available. Optimization of machining parameters is done to improve the product quality, as well as its productivity.

In this perspective, an attempt has been made to develop a vigorous approach for the optimization of multiple responses in GFRP composite drilling. For persistent quality change and logged off quality control, strategy of experimentation has been chosen in light of Taguchi's orthogonal configuration along with shifting procedure control constraints like, spindle speed, feed and drill diameter. A utility concept incorporated with Taguchi's reasoning has been proposed for giving possible intends to the important accumulation of more than one objective functions into an equal single execution index.

Keywords: GFRP, Drilling, Multi-Response Optimization, Taguchi, Utility Concept.

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Chapter1: Introduction

1.1 Composites

Composite materials are considered to have a very significant role in the area of advanced manufacturing systems/processes. A composite material is the response to demands for emerging technology. The market generates because of the rapid advancing in aircraft, aerospace, and automotive industries. Composites are highly considered because of their low specific gravity, as it makes them especially better in quality and modulus than numerous conventional materials, for example, metals. To develop new composite materials, it's basic to study about materials and comprehend their structure-property relationship. Continuous advancements in composite materials have let the application area spread in a diversified manner. As a fact, the significance of composites as an engineering material is mirrored, that now almost 17% of all those materials available in the market are composites *[Manocha and Bunsell. (1980)]*.

Composite materials are designed or engineered from two or more materials that constituents together and have different physical or chemical properties, remains distinct from the naturally visible (macroscopic) or infinitesimal (microscopic) scale in the final completed structure. The constituents do not dissolve or merge into one another although they act in concert and retain their individual identities.

Constituents are known to be the individual materials that contribute in making up composites. Composites may have two constituent elements: One material is as particulate, called the Reinforcement or discrete phase, i.e. fibers, particles, flakes, and, or fillers. Also the other is a strong formable, called the matrix or continuous (persistent) phase, i.e. polymers, metals, or ceramics. The matrix and Reinforcement meet in the district called, Interface. Typically, the constituents exhibit an interface between one another and can be physically identified. *[Chung. (2010); Harris (1999)]*

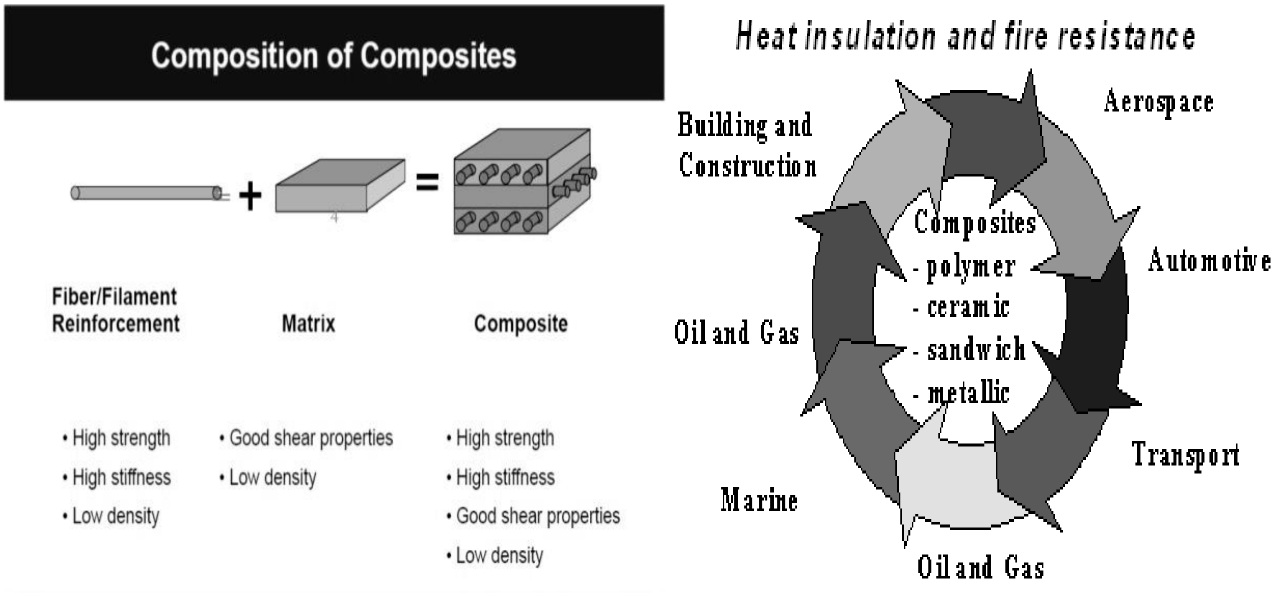


Fig1.1: Composition and use of Composites.

The Reinforcement is normally much stronger and stiffer than the matrix and give the composite its genuine properties. Reinforcements are holded by the matrix in a systematic example to form the desired shape. Matrix helps in transferring the load among the Reinforcement, as reinforcements are usually discontinuous. The primary focal points of composite materials are their great quality and firmness, joined with small concentration, when contrasted with mass materials, considering for a mass drop in the completed part. In any case, machining of the composite materials is not simple, as there is a striking contrast between the machining of conventional materials and composites. These differences are possessed because of the machining behavior of composites, which differs from one composite to other.

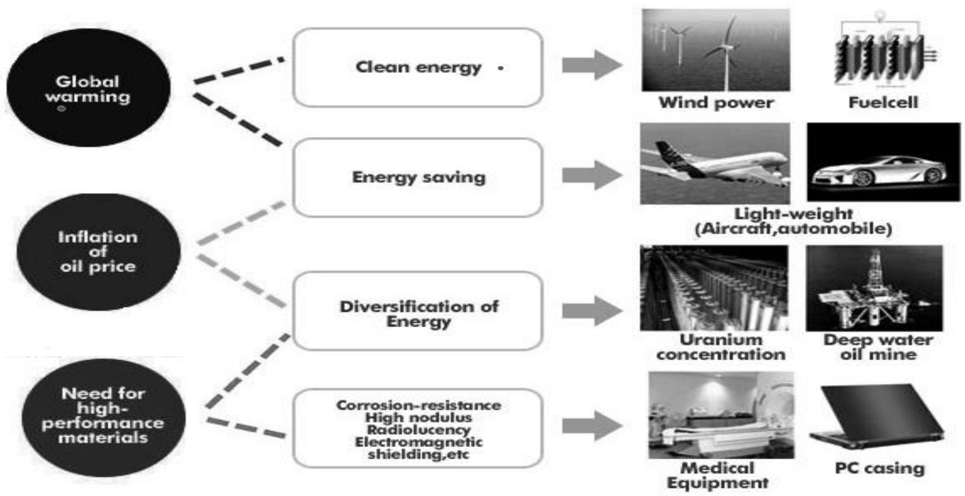


Fig 1.2: Applications of Composites.

The physical and mechanical properties of the composite depends to a great extent on the kind of fiber, the content of fiber, the orientation of fiber and variability in the matrix material. Composites can be classified as;

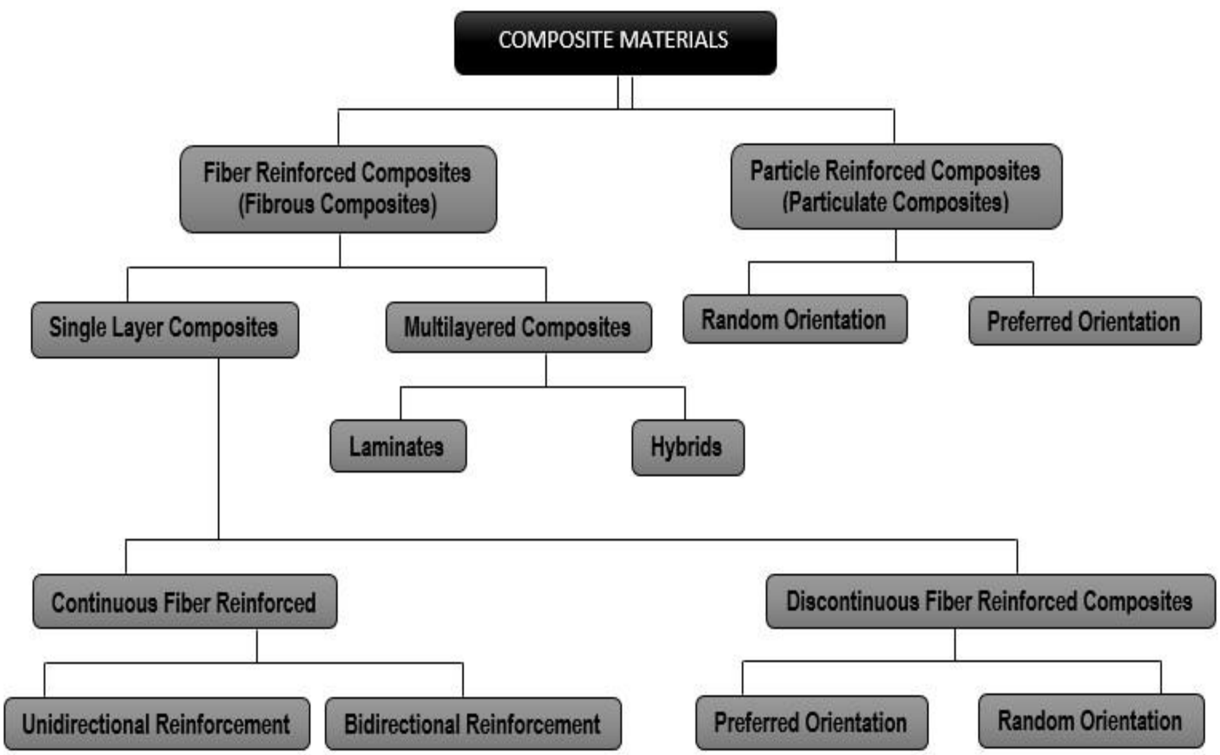


Fig. 1.3: Classification of composite materials.

1.2 Matrix

The solid material in which Reinforcement is implanted is called Matrix. It's the essential stage and totally uninterrupted, i.e. there is a way through the matrix to any point in the material, dissimilar to where two materials taken together. A Matrix is less hard, bendable material and is made up of lighter metal, for example, aluminum, magnesium, or titanium gives an agreeable backing to the Reinforcement in structural applications. It may have three essential material,

- Polymers
- Ceramics
- Metals

1.3 Material of Matrix

The matrix material is chosen in the wake of giving cautious thought to its properties, behavior, synthetic similarity, and capacity to wet the Reinforcement. Furthermore to its characteristics, properties and behavior of processing *[Mehrabian et al. (1974); Lloyd. (1990)]*. The best properties may be acquired in a composite in the wake of making the Reinforcement particulates and matrix as their physically and synthetically perfection would be prudent.

Many researchers proposed materials like Al, Ag, Cu, Fe, Mg, Ni, Pb, Sn, Si and Zn as the matrix material, depending on their oxidation and corrosion resistance properties. Among these, the most common metal alloys in use are based on Aluminium and Titanium as both of them are low-density materials and available in an extensive range of alloy compositions and commercially efficient. *[Taya and Arsenault (1989)]*

Other alloys have their own advantages and disadvantages. Like,

- Beryllium is the lightest in structural materials but extremely brittle, hence unsuitable for general purpose use.

- Magnesium is light but is highly reactive to Oxygen.
- Nickel and Cobalt based super alloys have the undesirable effect of oxidation on the reinforcing fibers at high temperatures.
- Aluminum contains property of good corrosion resistance, low density, high toughness, high conductivity, and combination of excellent mechanical and electrical properties, hence it is considered among the best materials for matrix *[Degischer (1997)]* and it's also inexpensive than other light metals like magnesium (Mg). Because of its corrosion resistance property, it can be used in different environments *[Sharma and Das (2009)]*.
- Magnesium has an advantage of having the right combination of low density and excellent machinability as compared with other structural materials *[Pedersen and Ramulu (2006)]*.

1.4 Reinforcement

It is the optionally scattered stage, installed embedded in the matrix in an irregular form and is generally harder and stronger than the continuous phase. Reinforcement does generally serve structural assignment i.e. reinforcing the compound but at the same time is utilized to change the properties of the material like; resistance to wear, coefficient of friction, or thermal conductivity. It helps in fortifying the composite and does additionally enhances the general mechanical properties of the matrix. It builds the stiffness and the capacity to resist the temperature, also bring down the thickness of Composites. In spite of the fact that the biggest change in properties (strength and firmness) is acquired with the introduction of fiber Reinforcement. The properties of fiber-reinforced composites are not isotropic. Reinforcement can either be particulate or fibrous. Approximately 90% of the Reinforcement being used these days are glass fibers. The explanation behind utilizing glass filaments is, they are solid, has good resistance to heat, and high electrical properties. FRP/ Composites with carbon fiber Reinforcement are additionally broadly utilized as they have astounding fatigue properties.

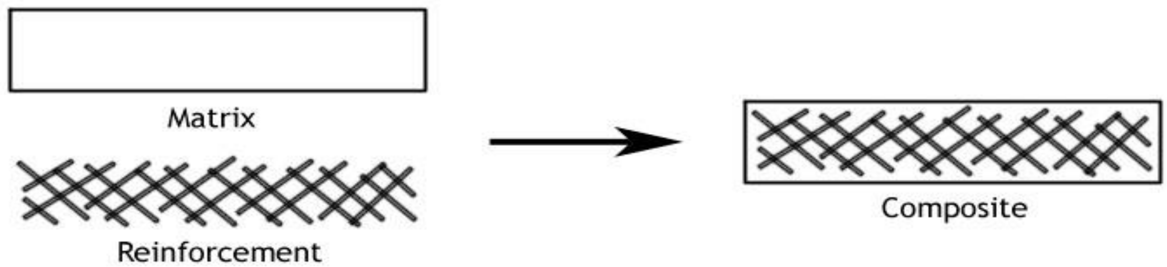


Fig 1.4: Formation of composite by matrix and reinforcement

The three essential courses of action of glass fiber Reinforcement are unidirectional, bidirectional and multidirectional.

- *Unidirectional Fiber:* These procurements give the best strength in direction towards the fibers. The fibers can be persistent or discontinuous, contingent upon specific needs and allows high Reinforcement stacking for maximum strengths.
- *Bidirectional Fiber:* Bidirectional plan gives the most astounding quality in two headings.
- *Multidirectional or Random Fiber:* These procurements give generously parallel quality in all headings of the finished part. Reinforcement are planned in such structures that they give adaptability to cost, quality, compatibility with the resin system, and process necessities. Various fibers are accumulated all the while into a strand and taken through the surface treatment procedure to encourage subsequent processing, keep up fiber integrity, and furnish compatibility. Then the strands are prepared into different types of Reinforcements. [*Ahamed et al. (2009); Guo and Derby (1995); Xia and McQueen (1997); Sun et al. (2011); Chawla and Shen (2001)*]

1.4.1 Thermoset Polymer

These polymers are generally found in a form of liquid or the solids having a low melting point. They combine with fibers easily. Thermoset fundamentally includes polymer that are cross-connected chains and get to be solid after a chemical response. In FRP/Composites, thermoset resins are most widely used. Polyesters have an advantage of easy caring, affordable cost, and dimensional security. They are the offset of good mechanical, substantial, and electrical properties and are not prescribed for utilization with solid alkalis. Other thermosetting resin systems are:

Phenolics: It's a good corrosive resistance with good smoke/flame and thermal properties.

Silicones: Its resistance to heat is high with low ingestion of water. It has an astounding dielectric properties.

Melamines: It has a high strength to impact and is also a good heat resistant.

Diallyl phthalates: It has good electrical protection with low water ingestion.

1.4.2 Thermoplastic resins

Thermoplastic polymers are the particular case that mellow and get to be liquids when heated for transforming and get to be strong when cooled. It's a reversible methodology. It permits a sensible level of procedure waste and reused material that can be recycled and does not have a critical impact on the finished item. Thermoplastic resins permits quicker moulding process durations as there is no chemical response in the curing methodology. As quickly heat can be exchanged, parts can be shaped.

Polypropylene and polyethylene are the most widely recognized thermoplastic resins utilized as a part of FRP/Composites in view of their great resistance to acids, alkalis and to organic solvents. The quick transforming could be possible on these materials as their generally low liquefying point permits it at a lower expense. Nylon and Acetal have high resistant to natural solvents.

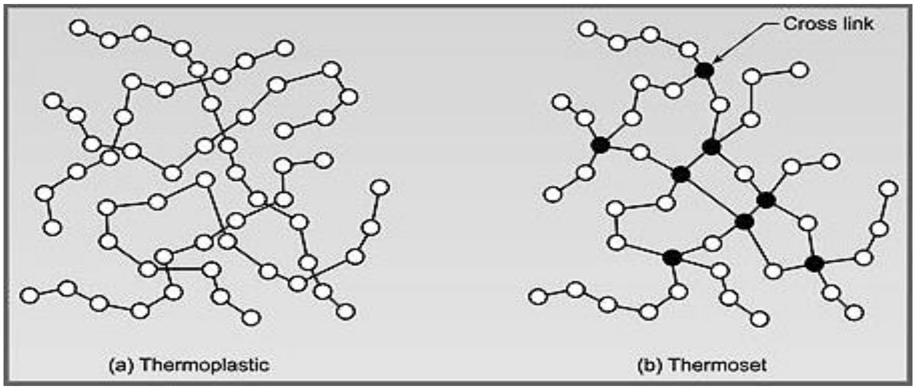


Fig 1.5: Molecular structure of Thermoplastic and Thermoset

1.5 Glass Fiber Reinforced Polymer

“Glass Fiber reinforced polymers" or GFRP (normally alluded to just as fiberglass) are a demonstrated and successful option that have various favorable circumstances over conventional reinforcement methods, giving structures a more drawn out service life. It utilizes glass fibers of textile grade.

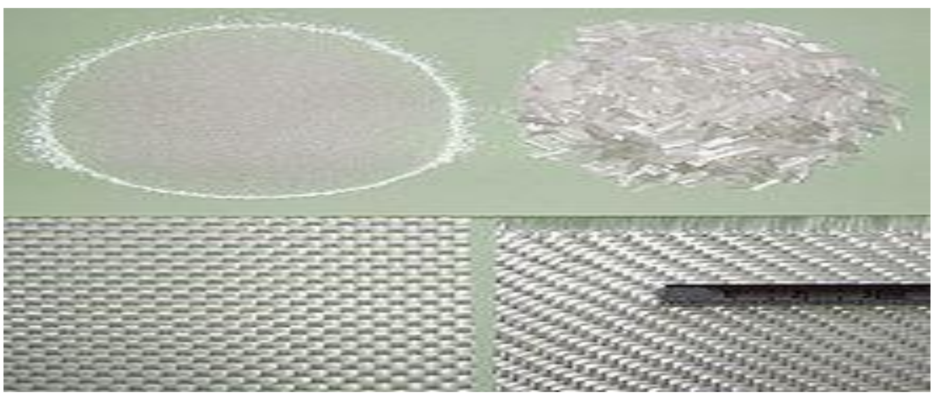


Fig 1.6: Glass Fiber Reinforced Polymer Sheet

Textile glass filaments are composed as mixes of Calcium Oxide (CaO), Aluminium Oxide (Al_2O_3), Boron Trioxide (B_2O_3), or Magnesium Oxide (MgO) in powder structure. Then heating of these mixtures are done by direct softening by considering temperature up to 1300 degrees Celsius, then utilization of dies is done to expel fiber of glass filament in different diameter measurement. These fibers are assembled into bigger strings by Roving methodology. Glass fiber is the most famous intends to reinforce plastic. Glass Fiber Reinforced Polymers are for all time impervious to chemical acids and alkaline bases; subsequently additional concrete cover, cathodic protection, and anti-shrink additives are not needed. GFRP essentially enhances the life span of engineering structures where corrosion is a major consideration.

1.5.2 Application of Glass Fiber

Glass Fiber is a gigantically flexible because of its light weight, inborn quality, inherent strength, climate safe completion and mixed bag of surface textures. The advancement of fiber-reinforced polymer for commercial utilization was widely examined in the 1930s. It was of noteworthy to the flying business. Amid World War II, fiberglass supplanted the molded plywood utilized in airship. Its first fundamental non-military personnel application was, building of pontoons and game car bodies, recently its utilization was grown to the automotive and sports gear areas and in airship production. Glass Fiber is additionally utilized as a part of telecommunications industry for covering radio wires, in light of its low signal attenuation property and RF permeability. Different use incorporate sheet-structure electrical separators and structural components usually found in power industry items.

Glass Fiber tanks at an Airport

Glass Fiber dome house in Davis, California

Fig. 1.7: Application area of Glass Fiber Composites

1.5.3 Advantages of GFRP

- **High Strength:** The strength quality to weight ratio of GFRP is high.
- **Lightweight:** GFRP contains very low weight per square foot that brings out speedier establishment, low auxiliary framing, and less transportation costs.
- **Resistance:** Unaffected by acid fall, GFRP resists salty water, compounds, and most chemicals.
- **Consistence Construction:** To frame a one piece watertight structure, Cupolas and Domes are resined together.
- **Ready to Mold Complex Shapes:** Any shape can or structure can be formed virtually.
- **Low Maintenance:** Research demonstrate that even after 30 years there is no loss in laminate properties.
- **Durability:** GFRP is highly durable just like Stromberg. And it can confront class 5 tropical storm Floyd with no harm.

1.5.4 Disadvantage of GFRP

- Few material systems cost Very high.
- Technology is still progressive towards it maturity.
- The method for Fabrication is sophisticated for fiber-reinforced systems.
- The service experience is limited.

1.6 Need of Machining of GFRP Composites

As discussed about Glass Fiber Reinforced Polymer (GFRP) due to their mechanical and physical properties, are now a days limitlessly utilized as a part of diverse commercial ventures particularly, aerospace, sports, automotive, and so forth. While making components or products, in a progressing methodology of easy assembly GFRP needs to experience different machining operations say, drilling, milling, turning, and so on. The machining of GFRP is likewise prescribed to control the surface quality for the functional perspective. The machining of fiber reinforced polymers are additionally important to figure out the close nett shape and to get exact fits.

There are couple of issues that happens while machining a GFRP composite. Delamination is a standout amongst the most discriminating issue happened while drilling a GFRP composite. GFRP's are delicate materials made up of filament of glass and while the machining processes these filaments may break undesirably as a result of the thrust generated. Consequently it's imperative to perform the machining operation at improved parametric settings.

1.7 Drilling

The cutting process drilling, uses an apparatus named drill bit to reduce or broaden a gap of round cross-segment in solids. The drill bit is a rotational cutting instrument, frequently multipoint. The bit is squeezed against the workpiece and turned at a rate differing hundreds to huge number (thousands) of revolution every minute, which tends to forefront against the workpiece and cut off chips from the opening (hole) as its drilled.

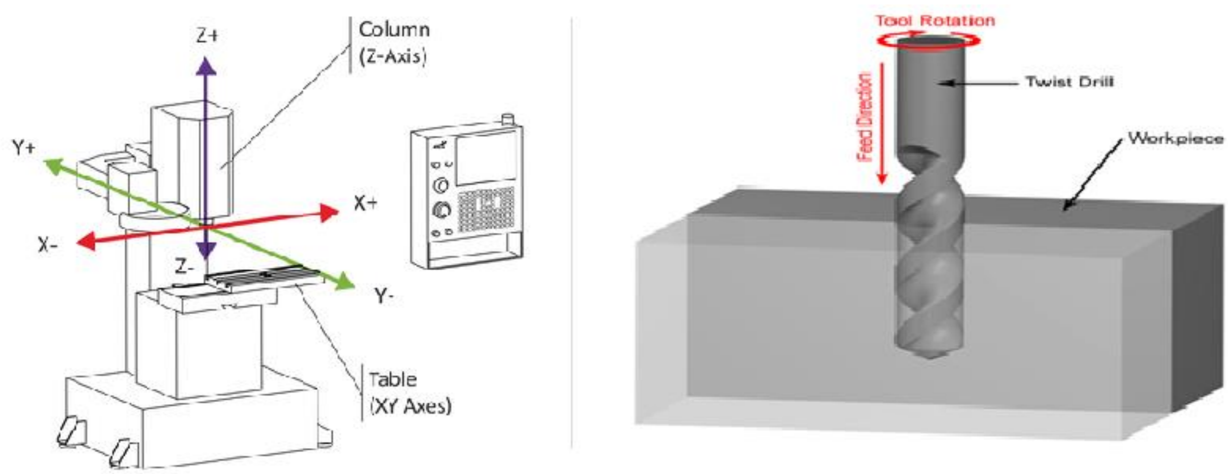


Fig. 1.8: Drilling operation performed through CNC twist drill.

Drilled holes are described by their sharp edge on the passage side and vicinity burrs on the outside. Drilling may influence the mechanical properties of the workpiece, which causes the workpiece to end up more powerless to erosion and break proliferation. Cutting fluid (liquid) is normally used to cool the drilling apparatus, build device life, expand pace and feed, expand the surface finish, and help in ejecting chips.

1.8 Computer Numerical Control (CNC)

CNC controls the limits and improvements of a machine instrument by technique for a set assignment comprising coded alphanumeric information. CNC can regulate the developments and movements of the workpiece or device. The input constraints are feed, depth (profundity) of cut, speed, and the capabilities for instance are, turning the spindle on/off, turning the coolant on/off.

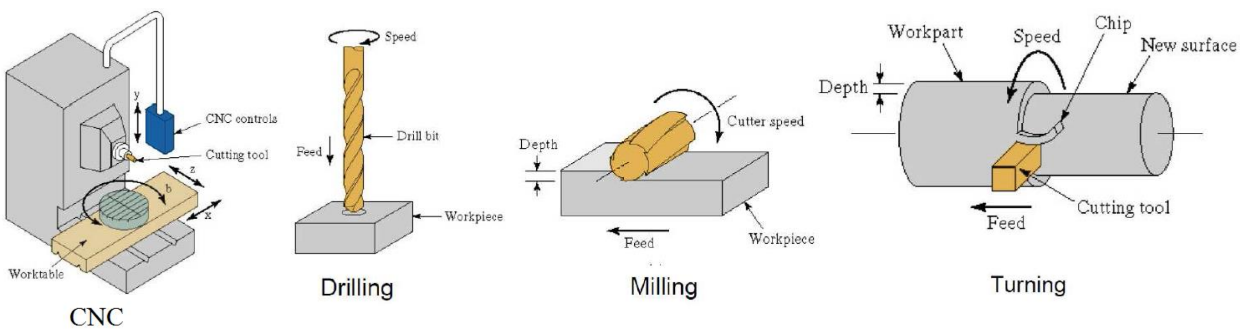


Fig 1.9: CNC machine and its different operations

1.8.1 Applications

The utilizations of CNC consolidate both for machine contraption and in addition non-machine tool zones. In the apparatus device class, CNC is broadly employed for lathe appliance, sheet-metal press working machine, drill press, crushing unit, milling machine, laser and tube bending machine and so on. Computerized device apparatuses, for example, machining center and turning center that alter the cutting devices naturally under control of CNC have been created.

The classification of non-machine apparatus, the applications of CNC include welding apparatus (resistance and arc), direction measuring machine, electronic assembly, tape placing and fiber twisting machines for composites and so forth.

1.8.2 Advantages and Limitations

The advantages of CNC are

(1) It is accurate even in high manufacturing.

(2) The generation time is very short.

(3) The adaptability to manufacturing is very high.

(4) Straightforward Fixturing.

(5) Contour machining from which machining up to 2 to 5 axis is possible.

(6) Human mistakes is reduced.

The downsides incorporate great cost, maintenance, and the prerequisite of an expert part programmer.

1.9 COMPONENTS OF A CNC

A CNC framework comprises of three vital parts;

i. ***Part program:*** It is a step by step instructions to be followed by the machine instrument. Every order suggests a position in the Cartesian coordinate framework (x, y and z) or movement (workpiece travel or cutting device travel), parameters of machining and capacity to turn on/off. The part program is composed by human efforts by utilizing computer supported language, for example, APT (Automated Programming Tool).

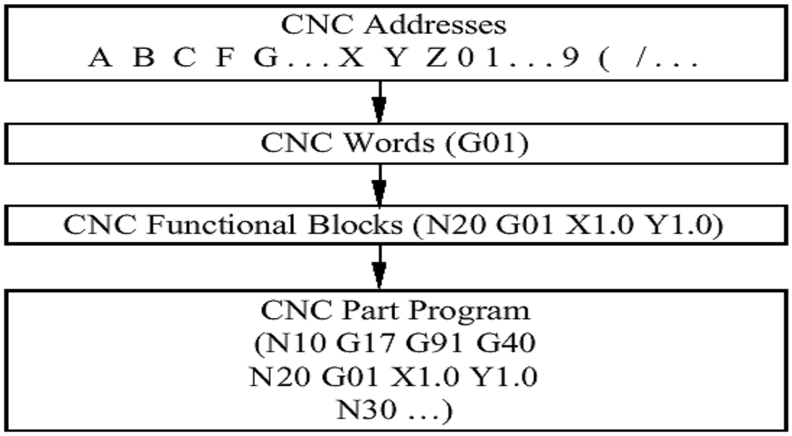


Fig 1.10: Part program structure used for CNC programming.

ii. ***Machine Control Unit (MCU):*** The machine control unit (MCU) is a small computer like device that stores the data-bits and executes the instructions into activities by the machine device. The MCU comprises of two primary units: the information handling (data processing unit-DPU) and the control loop unit (CLU). The DPU programming incorporates control framework application, algorithms of calculations, interpretation application that changes over the part program into a usable pattern for the MCU. Algorithm of interpolation is utilized to attain to smooth movement of the cutter and to alter part program (if there should be an occurrence of errors and changes). The DPU forms the processes from the part program.

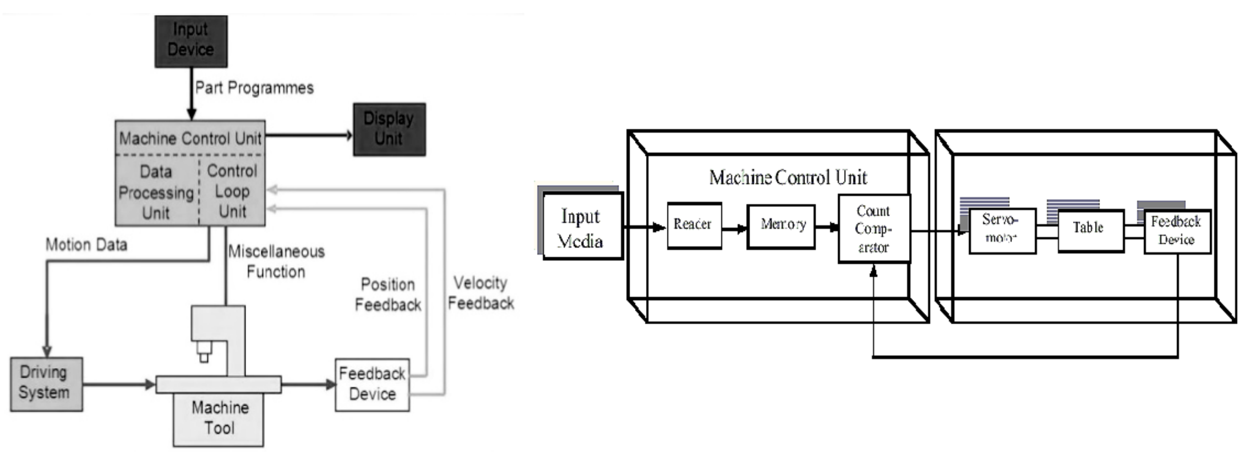


Fig 1.11. Machine Control Unit of CNC machine.

iii. ***Machine Tool:*** The machine instrument could be one of the accompanying: lathe, boring, drilling, processing (milling) machine, laser, plasma and direction measuring machine and so forth.

Chapter 2: Literature Review

Writing review of literatures is simply an accumulation of important outlines of papers or an expounded clarified reference index of different research compositions. An important writing is a great deal. ***Hart*** in 1998 characterized the writing or literature review as, the utilization of thoughts in the writing to legitimize the specific way to deal with the topic, the choice of methodology, and an exhibition that this exploration contributes something new. A methodological survey of past literature review is a pivotal try for any scholastic exploration. The necessity to reveal what is as of now known, in the collection of learning initiating any exploration study ought not to be underestimated.

To have better knowledge about the topic, its problems, the work approach and the progress in the area of research on the said subject few literatures were reviewed. The description of some of the important literatures is presented as follows.

Mathew et al. (1999) presented a trial experiment that demonstrates the impact of the geometry of a trepanning device on thrust and torque amid the drilling of unidirectional glass fiber-reinforced plastic (UD-GFRP) overlays. It is un-doubted that the best method for attaining to great quality holes while drilling fiber-reinforced plastics (FRPs) is by diminishing the thrust and torque. The tryouts have uncovered that the execution of the trepanning apparatus is better than that of ordinary twist drills regarding thrust, torque and hole quality. They finished up this trepanning apparatus created around 50% less push and around 10% less torque when contrasted with twist drills. The holes were discovered to be of good and worthy quality. ***El-Sonbaty et al. (2004)*** explored the impact of machining parameters on the thrust (push) force, torque and surface roughness in drill procedures of fiber-reinforced composite materials. These parameters incorporate cutting velocity, feed, drill size and fiber volume part. Results demonstrate that for epoxy resin, expanding cutting velocity has an unimportant impact on thrust force. The cutting speed and feed have an unimportant impact on surface roughness of epoxy resin. Then again for glass fiber reinforced composite (GFRP), the surface roughness was enhanced by expanding cutting speed. ***Tsao and Hocheng (2004)*** presented an expectation and assessment of delamination factor the utilization of twist drill, saw drill and candle stick drill. ANOVA has been done to analyze the effect of process parameters. The experiments were directed to study the delamination consider under different cutting conditions. The results demonstrated that the feed rate and the diameter of drill are perceived to make the most critical contribution to the machining performance. The research also highlighted to establish the relationship between feed rate, spindle speed and drill diameter with the actuated delamination in a carbon fiber reinforced (CFRP laminate. They finished up the candle stick drill and saw drill cause a little delamination component than twist drill. ***Singh and Bhatnagar (2005)*** proposed drilling of fiber reinforced plastic (FRP) composite materials is an area with plenty of inquiries. Drilling prompted damage is an investigation zone that has not been explored comprehensively. Tool point geometry is viewed as a main consideration that impacts drilling prompted harm. The outcomes additionally restored the cutting velocity to feed proportion as an essential variable that impacts drilling affected harm. ***Mohan et al. (2005)*** worked with the goal to locate the applicable components and blend of variables impact on the machining methodology to attain to small cutting torque and thrust. Investigation of response table shows that the thickness of specimen and drill size are the critical parameters of torque. ***Walia et al. (2006)*** recommended that for enhancement of methodology parameters, a methodology taking Utility hypothesis into account is used. And for synchronous optimization of more than one response attributes Taguchi quality loss function (TQLF) may be implemented. Three potential reaction parameters i.e., material removal, change in surface finish and dissipate of surface roughness over the finished surface of a sleeve type workpiece of brass are analyzed. Utility values in light of these reaction parameters have been dissected for improvement by utilizing Taguchi approach. An improved model in light of Taguchi's methodology and Utility concept are utilized to focus the ideal setting of the procedure parameters for a multi-characteristic product. ***Marques et al. (2007)*** utilized four distinct drills for machining the composite among them, three were commercial and one was extraordinary step (prototype). The outcomes were looked at on the premise of thrust force amid drilling and delamination. Keeping in mind the goal to assess damage, improved radiography is used. Results demonstrate that the model drill had empowering results regarding extreme thrust force and lessening delamination. Other than selecting cutting parameters, the decision of a devoted tool for drilling fiber reinforced laminates can be valuable. ***Krishnaraj (2008)*** led drilling trials utilizing standard Zhirov-point drill, twist drill, and multifacet drill, with broadly differing scope of feed rate and spindle speed. The impact of thrust, delamination and surface roughness is then examined. At high spindle rate, cutting force is discovered to be less and the unique geometry enhances the nature of the hole. Zhirov point drill and Multifacet drill is discovered better similarly as the delamination quality is concerned. Multifacet drill cuts the holes better than other drill geometries. This outcomes in a clean cut with a smooth surface. The delamination is less contrasted with other drill geometries. Zhirov point could be utilized to penetrate holes with lower thrust. The life of the Zhirov point is higher. . ***Routara et al. (2010)*** proposed utility integrated with Taguchi technique to examine the effect of machining variables in CNC end milling of UNS C34000 medium leaded brass. The study also focused for assessing the best process environment that could all the while fulfill various prerequisites of surface quality. In perspective of the reality, the conventional Taguchi system can't fathom a multi-target optimization issue; henceforth Utility theory has been coupled with Taguchi strategy. Accordingly, Utility based Taguchi technique has been discovered productive for assessing the ideal parameter setting. This methodology is sufficiently productive to illuminate a multi-response optimization issue. The said system can be prescribed for persistent quality change and off-line quality control of a methodology/product. ***Khan and Kumar (2011)*** managed the machining of glass fiber reinforced plastic (GFRP) composite material manufactured in their lab utilizing E-glass fiber with unsaturated polyester resin. Machining studies were done utilizing two distinctive alumina cutting instruments: in particular, Ti[C, N] blended alumina cutting device (CC650) and a SiC hair reinforced alumina trimming apparatus (CC670). The machining procedure was performed at diverse cutting velocities at steady feed rate and profundity of cut. It was observed that the abrasive wear is very smooth and less with the SiC hair reinforced alumina cutting apparatus than with the TiC or TiN blended alumina cutting instrument. ***Shivakumar and Guggari (2011)*** analyzed the effect of machining parameters viz. spindle speed, feed and drill diameter on the tool life during the machining of composites. It has been also noticed that clearing up the crack or the failure system is a vital issue in machining. Degradation happens as the aftereffect of environment-dependent synthetic or physical assault, regularly brought on by a degradation agent, and may include a few chemical and mechanical components. Composite materials have appealing aspects like the moderately high compressive quality, great versatility in creating thick composite shells, low weight and erosion resistance. In any case, material portrayal and failure assessment of thick composite materials in compression is still a thing of exploration. ***Palanikumar (2011)*** presented a methodology for the advancement of drilling parameters with different execution attributes taking into account the Taguchi's strategy with grey relational consideration. Taguchi's L_{16}, a 4-level orthogonal range has been utilized for the experimentation. The Drilling parameters, for example, spindle speed and feed rate are enhanced with thought of numerous execution qualities, for example, thrust force, workpiece surface roughness and delamination. The outcomes demonstrate that the execution of drilling procedure can be enhanced viably through this methodology. The request of the significance of the controllable elements in light of the grey relational rate is feed rate took after by speed. ***Budan et al. (2011)*** displayed a test result on the impact of fiber volume reinforcement on different parts of machining. Drilling investigations were performed to study the delamination, tool wear, hole quality and surface finish on GFRP composites. Results uncovered that the increment in fiber rate expanded the tool wear, delamination variable, surface roughness and minimizes the hole quality. Least surface roughness, better hole quality and tool wear were acquired for 30% fiber content composites. At the point when the fiber substance is low, heat accumulate at tool tip and noteworthy increment of temperature in work-piece advances plasticity by far reaching chain sliding. Henceforth, long chips were acquired. Though in higher fiber content composites, far reaching plasticity was lacking subsequently brittle ceramic strands were cracked effortlessly. ***Verma et al. (2011)*** proposed fuzzy inference system integrated with Taguchi approach in order to obtain the optimal machining condition during the turning of GFRP composites. In this study, spindle speed, feed rate and depth of cut have been taken into consideration to analyze their effect on surface roughness and material removal rate. ***Rajasekaran et al. (2012)*** recommended that for achieving better surface roughness, and dimensional precision, different methodology parameters, for example, cutting velocity, feed, profundity of cut must be inspected. They concentrated on forecast of machining parameters that yields better surface qualities. In view of correlations figured out from the analysis it was recommended that response surface procedure could be all around used for anticipating the surface roughness of fiber reinforced polymer composites. ***Murthy et al. (2012)*, ** examined the impact of methodology parameters, for example, spindle rate, drill diameter, feed, material thickness and point angle on thrust power and torque. The glass fiber reinforced polymer (GFRP) composite was drilled utilizing strong carbide drill and all parameters were examined. The ideal mix of methodology parameter settings was discovered utilizing the reconciliation of Taguchi technique and Response Surface Methodology. It has been concluded that thrust power is essentially affected by spindle speed, and they are conversely relative. ***Goyal et al. (2012)*** exhibited a view that for optimization of multi-response process parameters, center ought to be on the subjective and practical learning accessible about the procedure. Considering limits, a methodology in view of a Utility theory and Taguchi quality loss function was applied. All the input parameters fundamentally enhance the utility funtion and S/N proportion containing three quality features. ***Kumar et al. (2012)*** mulled over the impact of machining parameters on cutting forces i.e. tangential, radial and feed force in different conditions. A conclusion was made, that the wet environment reduces the tangential force while the cool cutting environment reduced the feed force and the dry environment reduces the radial force. ***Madhavan and Prabu (2012)*** reported the impact of thrust while drilling holes of 10mm diameter in a 20mm thick Carbon Fiber Reinforced Plastic composite laminate utilizing the HSS, Solid Carbide (K20) and Poly Crystalline Diamond drills. The examination has uncovered that the sort of drill geometry influences the thrust force essentially followed by the feed rate and the velocity. Medium cutting speed and feed rate gave ideal thrust force regardless of the drills utilized. Huge lessening in expense and timing can be attained to by utilizing this reaction surface model. ***Castro et al. (2013)*** concentrated on the ampleness and advantages of joining glass fiber reinforced polymer (GFRP) waste materials into polyester based mortars, utilized as sand totals and filler substitutions. New materials detail and in all definitions a polyester resin network was adjusted with a silane coupling specialists to enhance binder interfaces. Results demonstrate that the incomplete substitution of sand totals by either kind of GFRP recyclates enhances the mechanical performance of resultant polymer mortars. This study plainly distinguishes a promising waste administration solution for GFRP waste materials by adding to a financially savvy end-use application for the recyclates. ***Ali et al. (2013)*** surveyed the impact of milling and drilling parameters on hole making procedure of woven overlaid Glass Fiber Reinforced Polymer material. A factual methodology is utilized to comprehend the impacts of the control parameters on the response variables. The outcomes demonstrates that the milling procedure is more suitable than drilling methodology at high state of cutting speed and low level of feed rate. The cutting quality (least surface roughness, least distinction in the upper and lower dia) is of discriminating significance in the manufacturing business, particularly for exact assembly. In the drilling methodology, normal thrust force can be diminished by decreasing the cutting velocity, while in milling procedure, machining power can be decreased by lessening the feed rate. In both milling and drilling methodology, productivity can be expanded by expanding speed and feed rate. ***Babu and Sunny (2013)*****,** displayed the investigation of composite delamination happened while drilling, by directing tests utilizing Taguchi's L_{25}, 5-level orthogonal array. Analysis of Variance (ANOVA) was utilized to evaluate the information acquired from the trials. Lastly finding the ideal drilling parameters in drilling GFRP composite materials. Trials were additionally led to figure out if fluctuating feed & spindle rate amid drilling could decrease the delamination. It is reasoned that the drilling affected delamination increments with spindle speed and reductions with feed rate. ***Ramesh et al. (2013)*** examined a non-covered Glass Fiber Reinforced Plastic (GFRP) composite produced by pultrusion procedure was drilled with a covered carbide drill. The ideal level of procedure parameters towards least thrust force, least torque and lower harm component were obtained to accomplish deformity controlled drilling of GFRP composites. Subsequently, it is concluded that impact of feed and speed on element at entry and exit of non-covered GFRP composites was inconsequential. The procedure parameters, feed and speed, are physically and factually inconsequential in affecting the harm factor. ***Kumar et al. (2014)*** attempted to streamline process parameters in particular, cutting speed, feed, chisel edge width and point angle in drilling of glass fiber reinforced polymer (GFRP) composites. The outcome demonstrates that feed rate is the most impacting component for the torque, thrust force took after by speed, point edge and chisel edge width. While cutting speed is the variable influencing the torque, speed and the circularity of the hole took after by feed, point angle and chisel edge width. The outcomes uncover that feed rate and velocity are the hugest impacting on the torque, thrust force and surface finish. Speed and chisel angle width are most impacting on the circularity mistake of the hole. ***Gopinath and Suresh (2014)*** proposed that with a specific goal to drill holes effectively with the minimum waste and deformities, it is crucial to comprehend the machining conduct of FRP. For which the procedure parameters explored are spindle speed, drill diameter and feed rate. Static and dynamic investigation is produced to anticipate torque and thrust force in drilling of FRP composites. The outcomes uncover that the fuzzy based model is suitable for anticipating the torque and thrust force in drilling of composites. Likewise the, use of this framework can enhance the nature of drilled part; if online checking is presented. ***Sen and Reddy (2014)*** presented Natural fiber composites based woven jute and also heat treated woven jute, with epoxy resin as matrix prepared and tested for its mechanical properties. The goal of this study was to elucidate the adequacy of characteristic bio-based woven jute FRP for shear strengthening purpose. The study concluded that the woven jute FRP retrofitting scheme had several advantages over carbon and glass FRP retrofitting system and converted brittle failure mode of beams to the ductile failure mode. Unlike carbon and glass FRP retrofitting the beams did not undergo any sudden de-bonding, or delamination or FRP rupture and depicted a complete ductile failure mode with high deflections. ***Shah and Tarfaoui (2014)*** aimed at the development of an approach for the characterization of composites under cyclic loadings. An investigation was performed on the reduction of stiffness and the heat generated during the progression of damage. From this study, it was concluded that, by using plasticity curves one can determine the load threshold even in the damaged state where the structure would sustain under cyclic loading. ***Abhishek et al. (2014)*** adopted the principal component analysis coupled with Taguchi approach to assess the optimal parametric combination in drilling of CFRP composites.

Aforementioned literature highlights effects of machining variables in machining of GFRP composites. Here, this dissertation highlighted the effect of process parameters particularly spindle speed, feed and drill diameter in drilling of GFRP composites. This present study adopted the utility concept integrated with Taguchi approach in order to evaluate the optimal parametric combination.

Chapter 3: Methodology

3.1 Introduction

In optimization, maximizing or minimizing is done of a real function by systematically choosing the given values from an allowed dataset and calculating the value of the desired function. While generalizing the optimization techniques and theory to some other formulations, it's found that it comprises a remarkable area of applied mathematics. A good variety of problems in practical that involves decision-making (analysis or system design) can be converted in the form of a mathematical problem of optimization, or as a multi-response optimization problem. Numerical optimization is now a valuable tool in certain areas. It's also widely used in engineering, automation of electronic design, automatic control systems, and design problems to be optimized in the field of civil, chemical, mechanical and aerospace engineering. Since 1940, a tremendous effort has been made to develop algorithms to solve various classes of problems in optimization, property analyzing, and in the development of real software implementations. In this view, the objective is to find a model, from available potential models, which would fit best with the observed data. Here the parameters are the variables in the model. To determine the factor level setting of quality characteristics, it is optimized using utility concept. Utility Concept is additionally used to consolidate the numerous responses in a solitary, known as multi-response performance characteristics Index (MPCI). Then, an empirical relation in process parameters and MPCI is obtained applying Taguchi methodology. Now, optimal settings from the technique are analyzed. By developing a valid model, it helps in searching the optimization landscape, so the best possible combination of the parametric results bests quality characteristics.

3.2 Utility concept

The Utility may be characterized as the product's convenience or a reference process up to the desires of the client. The general legitimacy portrayed of a product or methodology may be spoken to in a unified index, which is characterized as Utility Index. Utility Index is the entirety of individual utilities given for different quality (attributes) of the Product or methodology. The procedural method for Utility approach is that a response of every quality trademark is changed into an index which is standard for all.

In the event that X_i is the effectiveness measure of a trait (attribute) i, characteristics assessing the result space, then the Utility function may be communicated *[Bunn (1982), Routara (2010), Abhishek (2012)]* as:

$$U(X_1; X_2; X_3 \ldots\ldots X_n) = f\,[U_1(X_1); U_2(X_2) \ldots\ldots U_n(X_n)] \tag{1}$$

Where U_i (X_i) is the utility of the i^{th} trait.

The general utility capacity is the total of individual utilities if the traits are free and is given as:

$$U(X_1; X_2; \ldots\ldots X_n) = \sum_{i=1}^{n} U_i(X_i) \tag{2}$$

The general Utility capacity in the wake of allocating weights to the traits can be communicated as:

$$U(X_1; X_2; \ldots\ldots\ldots X_n) = \sum_{i=1}^{n} [W_i U_i(X_i)] \tag{3}$$

Where W_i is the weight allocated to the attribute i^{th}; the aggregate of the weights for all the traits must be equivalent to 1.

3.2.1 Determination of Utility value

To discover the estimation of Utility, inclination scale is intended for every quality characteristic. Two self-assertive numerical qualities (preference number) 0 and 9 are appointed to the simply satisfactory and the best estimation of the quality characteristic, separately. The preference number (Pi) may be communicated by a logarithmic scale as; *[Gupta and Murthy 1980; Kumar et al. 2000]*

$$P_i = A \times \log \frac{X_i}{X_0} \tag{4}$$

Where,

X_i is the estimation of any quality characteristic or trait i.

X_0 is the simply worthy estimation of quality characteristic or trait i.

A is constant.

The estimation of A can be found by the condition, $X_i = X^*$

(Where X^* is the ideal or best esteem value, got from the affirmation trials run at ideal parameter settings for the individual response characteristic). *[Goyal et al 2012; Goyal et al 2011]*

Then ***Pi* = 9.** Therefore,

$$A = \frac{9}{\log \frac{X_i}{X_0}} \tag{5}$$

In different quality attributes like, Lower-is-Better (LB), Higher-is-Better (HB), and Nominal-the-Best (NB) recommended by Taguchi, the Utility function would be Higher-the-Better sort. Henceforth, if the quality capacity is augmented, the quality characteristics considered for its assessment will naturally be optimized.

In this methodology of Utility, estimation of individual reactions is gathered to compute overall Utility index. Overall Utility Index serves as the single target capacity for optimization.

3.3 Taguchi method

In late 1940's as an analyst in Electronic Control Laboratory in Japan, Dr. Genichi Taguchi acquainted a measure with assess the outline parameters affect on quality attributes, it was called "Taguchi's logic". An effective apparatus to create quality assembling framework and its hearty configuration improves the efficiency of building. The outline of Taguchi's logic guarantee consumer loyalty, by taking the clamor elements (variety in assembling, variety in the earth) into record. It is a dynamic technique that improve quality and brings down the item cost, all the while. *[Roy 2001; Dean 1992]*

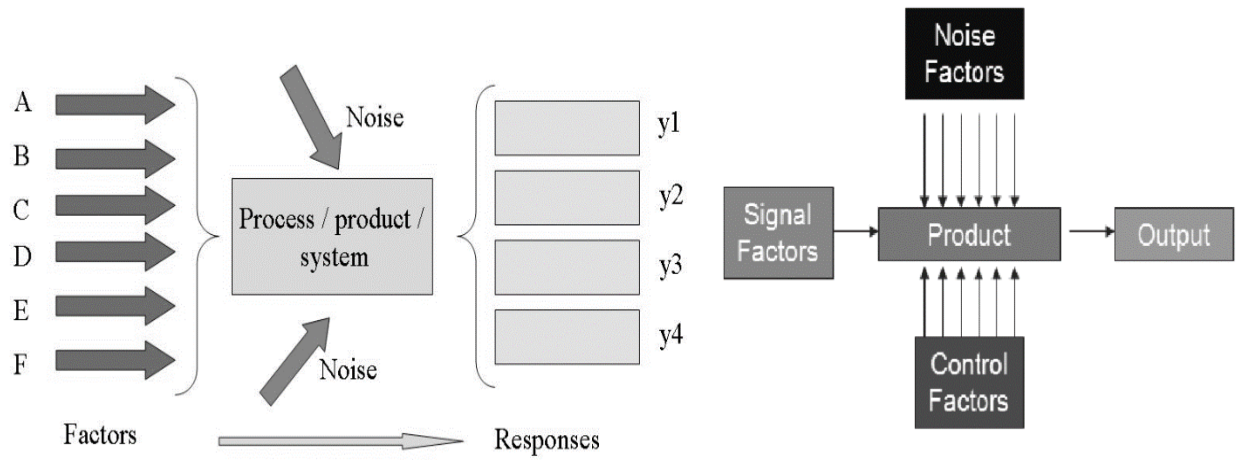


Fig 3.1: Taguchi's phenomenon of signal and noise.

Taguchi has proposed a three-stage outline operation to locate the nominal qualities for particular parameters simultaneously: system plan, parameter configuration and tolerance plan. Taguchi characterizes a performance measure, signal-to-noise (S/N) proportion and chooses the parameter ranks which amplifies the proportion. The term signal speaks to the square of the mean estimation of the quality characteristic, while noise is a measure of the variability of the characteristic. *[Mitra 1993]*.

3.3.1 Performance evaluation

In order to evaluate the optimal parameter setting, three categories of signal-to-noise ratios is considered. Such as,

- *Lower-is-better (LB)*
- *Higher-is-better (HB)*
- *Nominal-the-best (NB).*

➢ The higher-is-better (HB) S/N proportion is given by,

$$S/N\ Ratio = -10\log\frac{1}{n}\sum y^2 \tag{6}$$

➢ The lower-is-better (LB) S/N proportion is given as,

$$S/N\ Ratio = -10\log\frac{1}{n}\sum\frac{1}{y^2} \tag{7}$$

➢ The nominal- is-Best (NB) S/N proportion is given as,

$$S/N\ Ratio = -10\log\sum\frac{y}{S_{y^2}} \tag{8}$$

Where y indicates the estimation of the response for replicate i, and n is the quantity of replicates. The Taguchi system is concerned with the improvement of a solitary performance characteristic. There is a loss work (function) that portrays the deviation from the target and further changed into S/N proportion. The changed S/N proportion is additionally characterized as the quality assessment index.

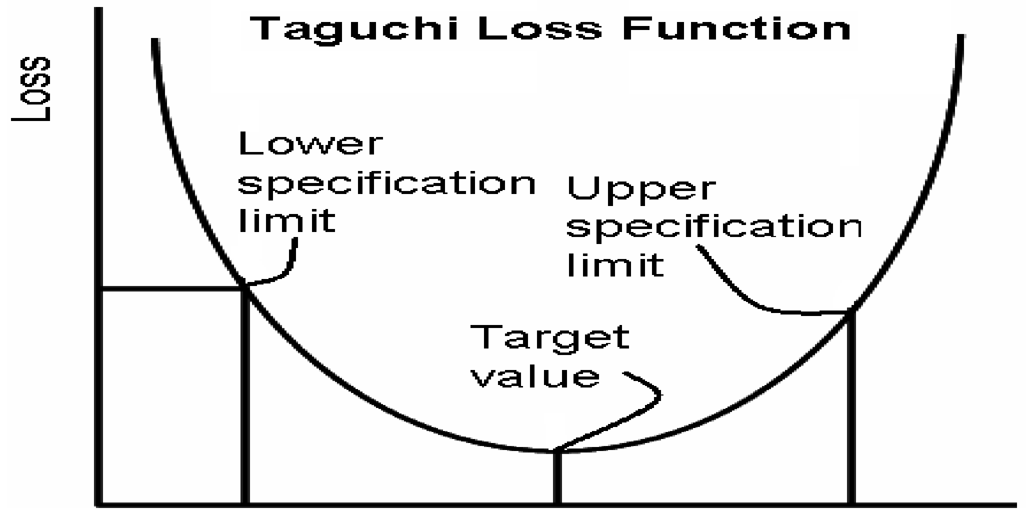


Fig 3.2: Taguchi's Quality Loss function

The minimum variety and the ideal configuration are gotten by examining S/N proportion. The higher the S/N proportion, the more steady the attainable quality. It likewise lessens the sensitivity of the framework performance. [*Tsui 2007; Mahapatra and Patnaik 2007]*

L = Loss associated with producing outside of tolerance limits in the traditional quality loss function.

L (x) = Loss associated with producing anything other than the nominal specification in the Taguchi Loss Function.

LTL = Lower tolerance limit.

UTL = Upper tolerance limit.

N = Nominal specification

d = Difference between nominal specification and tolerance limit

Throughout Taguchi system orthogonal arrays are utilized, that analyzes a substantial number of variables with less trials. The conclusions procured from less tests are substantial over the complete domain of control variables and their level settings. The S/N proportion considers the mean and the variability both, of the response data. After the measurable investigation of S/N proportion, an Analysis of Variance (ANOVA) is performed to gauge the relative significance of different variables and for figuring the fluctuation of error. In this way, a test affirmation is run to affirm the ideal conditions proposed, to enhance the project. If the expected improvements match, the proposed optimum conditions are adopted.

Chapter 4: Experimental Setup Details

4.1 Maxmill CNC

MAXMILL is a numerically controlled machine tool used for machining parts in every industrial field featuring high-speed, high-accuracy and high-productivity. It performs drilling, parting, boring, roughing, chamfering, tapping of circular and rectangular workpiece using CNC programming and operating software. Description of the CNC used is as follows;

***Standard Equipment*:**

- MAXMILL 3 axis CNC milling machine with Fanuc Oi Mate MC Controller.
- Machine Operator Panel.
- Central Automatic Lubrication System.
- Flood Coolant System.

Optional Equipment:

- ATC (Automatic Tool Changer)
- Pneumatic Vice.
- Panel Cooler.
- Auto Door.
- Servo Stabilizer.

Fig4.1: Maxmill CNC apparatus.

4.1.1 Machine Specifications

Table 4.1: Specifications of Maxmill CNC apparatus

X-Axis Travel (Longitudinal Travel)	**300 mm**
Y-Axis travel (Cross Travel)	**250 mm**
Z-Axis travel (Vertical Travel)	**250 mm**
Clamping Surface	**500*350 mm**
T-Slots (No.*Size)	**3*14 mm**
Repeatability	**±0.005 mm**
Positional Accuracy	**0.010 mm**
Coolant Motor	**RKM 02505**
Motor Power	**0.37 kW**
Tank Capacity	**110 LTR (Filter & Tray)**
Table Size	**500*350 mm**
Weight of table	**35 kg**
Load on table	**200 kg**
Rapid Feed	**10 m/min**
Stroke	**300 mm**
T-Slots	**14-3 Nos.**
Servo Motor	**FANUC β 4/4000i s**
Saddle Size	**468*350 mm**
Weight of Saddle	**50 kg**
Load on Saddle	**300 kg**
Rapid Feed	**10 m/min**
Stroke	**250 mm**
Servo Motor	**FANUC β 4/4000i s**
Column Size	**400*363*850 mm**
Rapid Feed	**10 m/min**
Stroke	**250 mm**
Servo Motor	**FANUC β 4/4000i s**
Electrical Specification	
Power Rating	**415V, 3φ, 15kVA**
Axes Motor	**FANUC Servo Motorβ 4i Series**
Spindle Motor	**FANUC Spindle Motorβ 3i Series**

4.2 Work piece and Tool material:

In this study, GFRP composite plates (5 mm thickness; supplied by Samtech. Engg. & Co. (P) Ltd., Ghaziabad, UP, India) have been used as work piece material. TiAlN coated solid Carbide drill bit [Manufacturer: WIDIA-Hanita] of different drill diameter 6 mm and 8 mm has been utilized for performing drilling operations (Fig. 4.2). Values of thrust and torque have been measured by using Digital Drilling Tool Dynamometer [Model No. MLB-DTM-Dl-3; Make: MEDILAB ENTERPRISES, Chandigarh, INDIA].

Fig 4.2: Carbide drill bit with TiAlN coating of dia 8mm & 6mm respectively

Fig 4.3: Digital drilling tool dynamometer.

4.3 Design of Experiment:

Design of experiment (DOE) is a scientific approach to deal with study the impact of different variables all the while. DOE has advantages of less number of experiments needed for preciseness in effect estimation, improvement quality of a product or methodology. Drilling is such a methodology in which various control factors calculates aggregately the output responses. Hence, in the present work one statistical technique called Taguchi method integrated with Utility concept is used to optimize the process parameters leading to the improvement in quality characteristics of the part under study. The most important step in the DOE lies in the selection of the control factors and their levels. Drilling process has large number of process parameters but based on different literature review three machining parameters namely, Feed (f), Spindle Speed (N) and diameter of the drill bit (d) are identified. Feed and spindle speed are set at four levels while diameter of the drill bit is set at two levels, as shown below in the table;

Table 4.2: Details of machining parameters

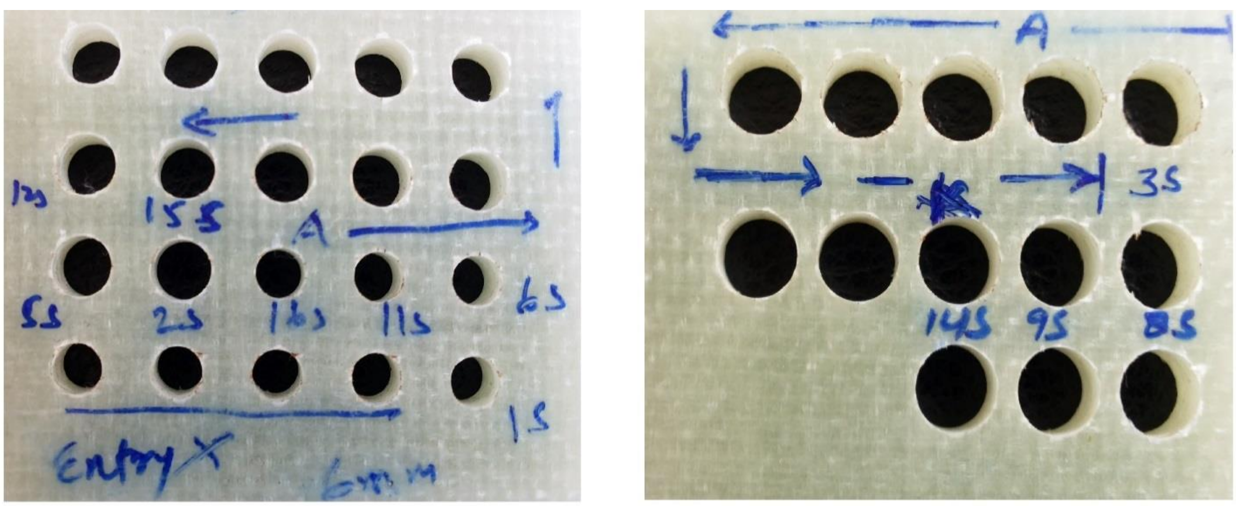
Sl. No.	**N (rpm)**	**F(mm/min)**	**D (mm)**
1	800	200	6
2	800	250	6
3	800	300	8
4	800	350	8
5	1000	200	6
6	1000	250	6
7	1000	300	8
8	1000	350	8
9	1200	200	8
10	1200	250	8
11	1200	300	6
12	1200	350	6
13	1400	200	8
14	1400	250	8
15	1400	300	6
16	1400	350	6

Chapter 5: Data Analysis

5.1 Introduction

This chapter comprises the experimental findings. The data are plotted and also presented in the format of the table and graphical methods. The experimental data are examined and analyzed in details. Optimal parameter settings are calculated by hybridizing Taguchi with utility concept. Analysis of variance is performed to get the commitment of parameters. An affirming result demonstrates the legitimacy of the ideal results.

Firstly the GFRP work-piece is drilled under given parameters, with the help of CNC machine and carbide drill bit, coated with TiAlN.



d = 6mm d = 8mm

Fig 5.1: Drilled work-piece with different drill bit dia.

Three procedure parameters (components) considered in this study are Speed (N) in rpm, feed (f) in mm/min, and drill diameter (d) in mm. The tests are led, and reactions are measured as Torque, Thrust, Surface Roughness, and Delamination. The reactions are changed over to signal-to-noise proportions. For all the reactions lower-is-better sort is considered to change over reactions into S/N proportions.

Table 5.1: Design of Experiment (L_{16} OA)

S. No.	N (RPM)	F(mm/min)	D (mm)
1	800	200	6
2	800	250	6
3	800	300	8
4	800	350	8
5	1000	200	6
6	1000	250	6
7	1000	300	8
8	1000	350	8
9	1200	200	8
10	1200	250	8
11	1200	300	6
12	1200	350	6
13	1400	200	8
14	1400	250	8
15	1400	300	6
16	1400	350	6

With given sets of process parameters (factors) drilling experiment using CNC is performed.

Responses in the form of thrust and torque are measured.

The work-piece is then cut down vertically to measure the Surface Roughness, with the help of *Tally Surf*, as its one of the responses that have to be optimized in this experimentation.

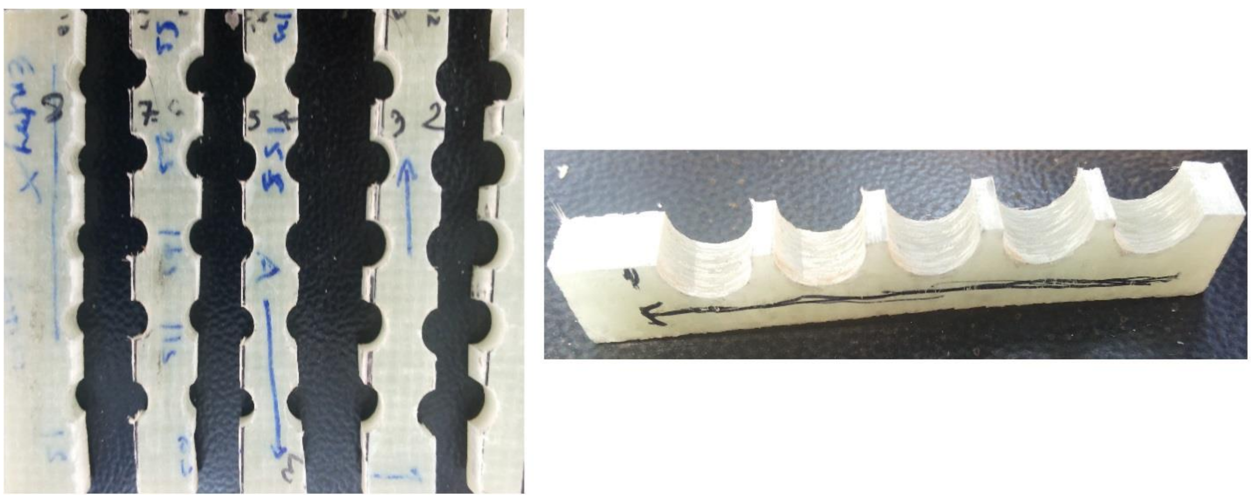
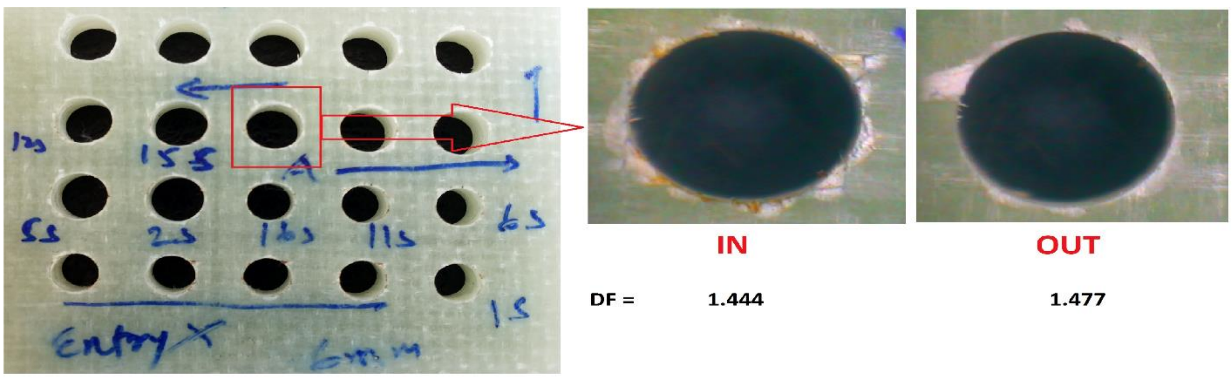


Fig 5.2: Measurement of Surface Roughness of the work-piece.

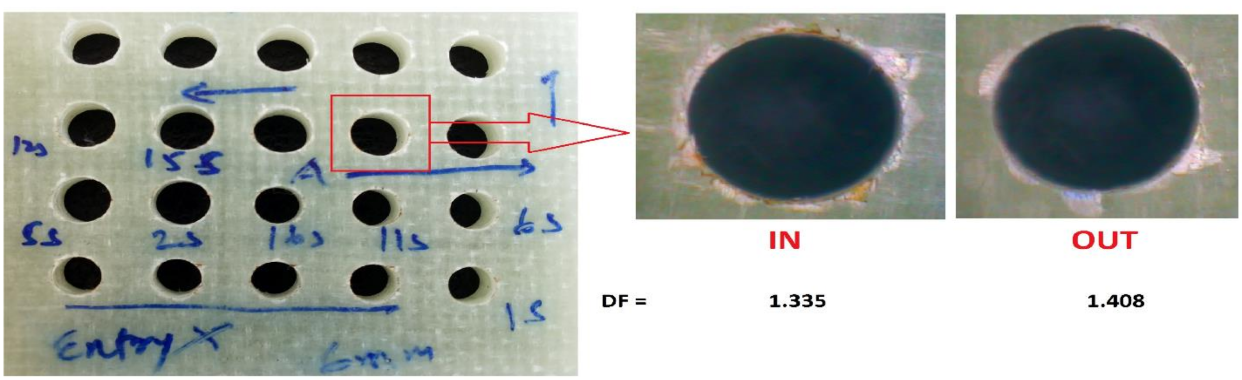
5.2 Delamination Factor

Among the imperfections brought on by drilling, delamination seems, by all accounts, to be of generally precarious. Delamination can bring about a dropping of bearing quality and can be undesirable. The level of delamination could be dictated by delamination variable, which is characterized as the proportion of extreme diameter, D of the harm zone around the gap to the hole diameter, d.

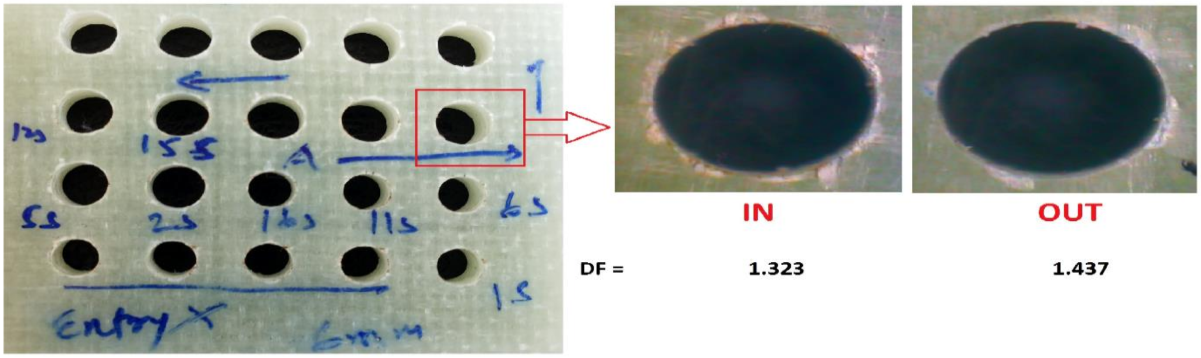
$$F_d = D / d$$



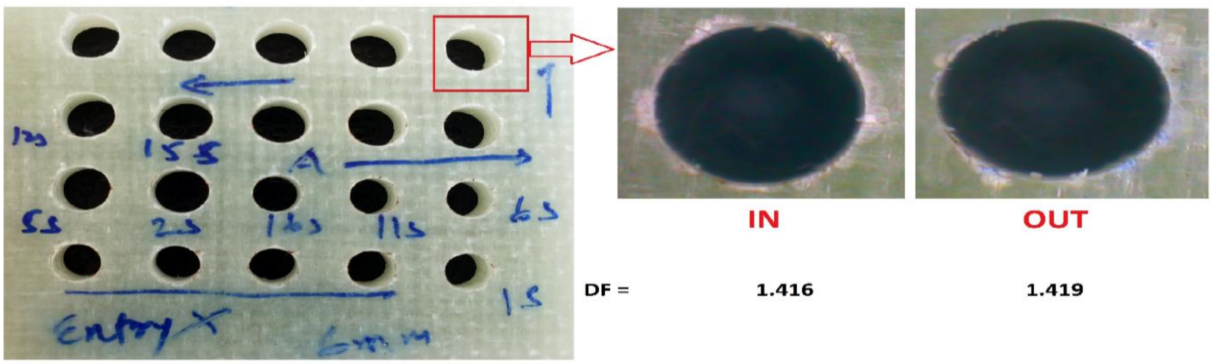
Experiment Run No: 1



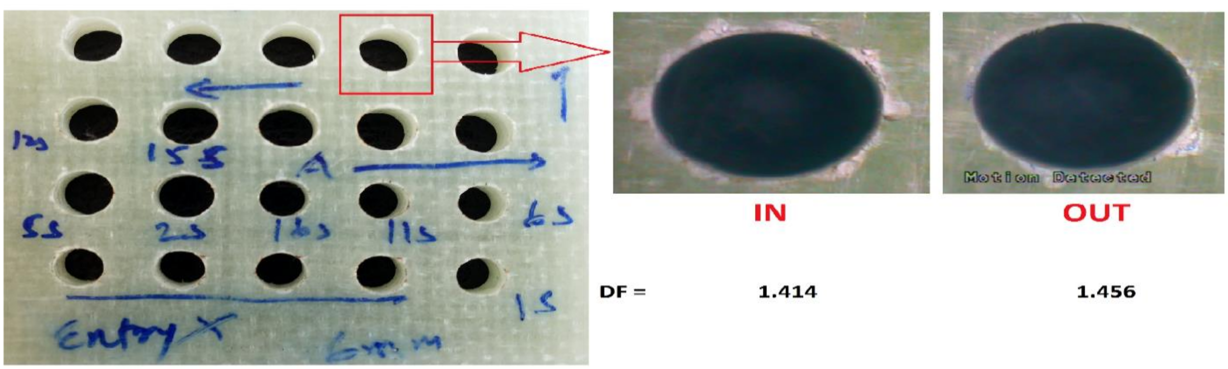
Experiment Run No: 2



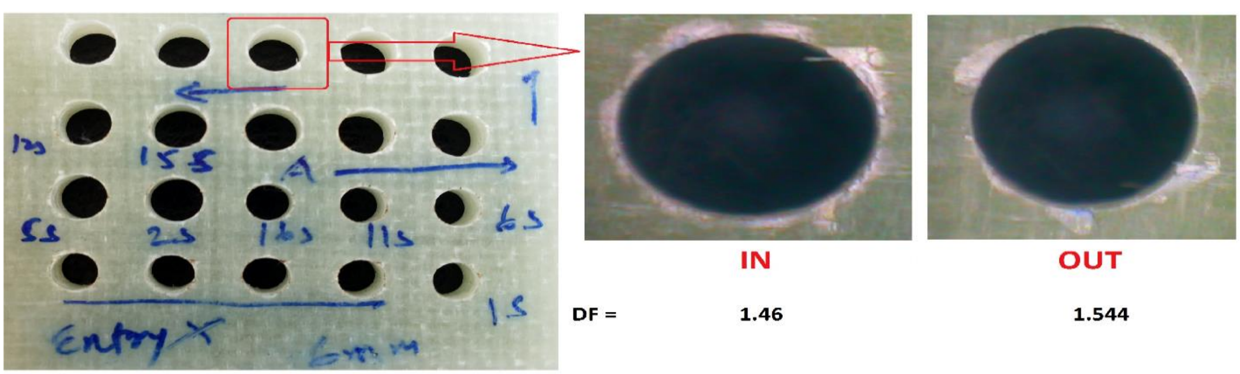
Experiment Run No: 3



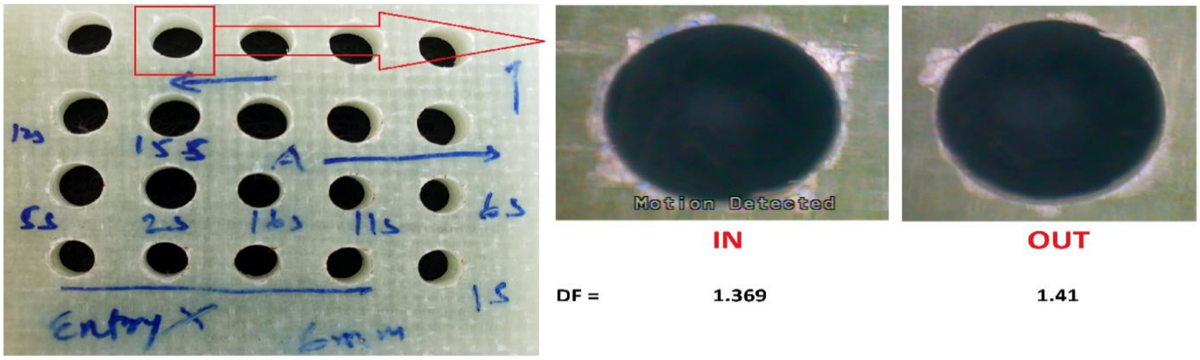
Experiment Run No: 4



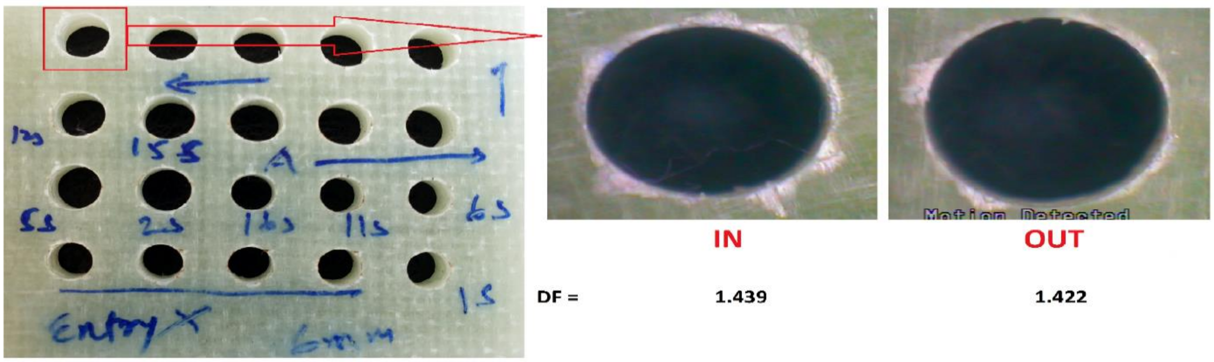
Experiment Run No: 5



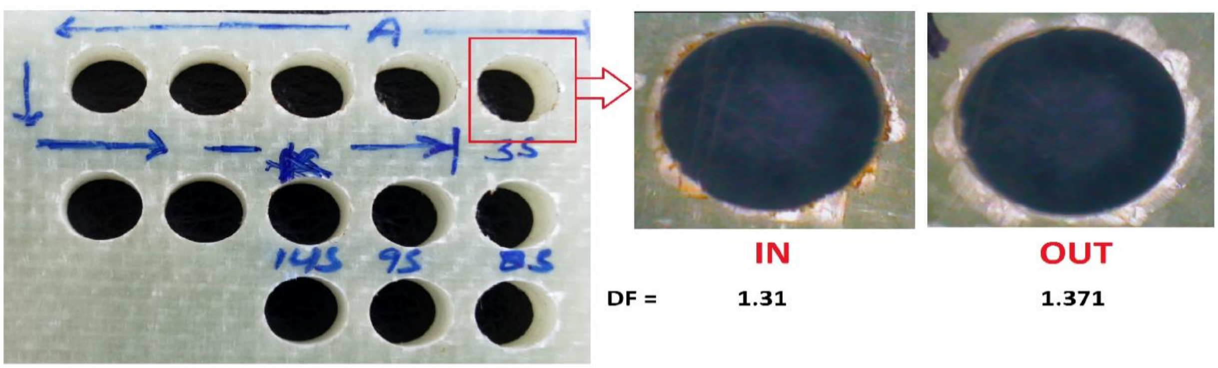
Experiment Run No: 6



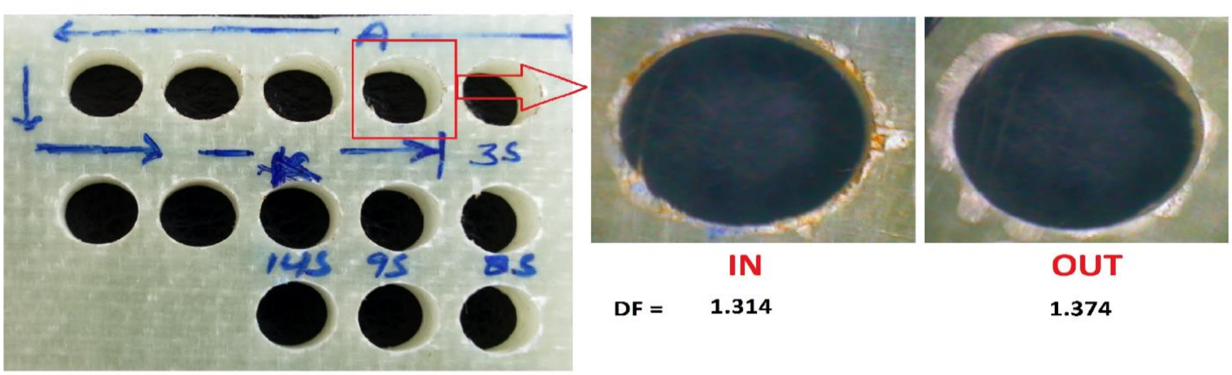
Experiment Run No: 7



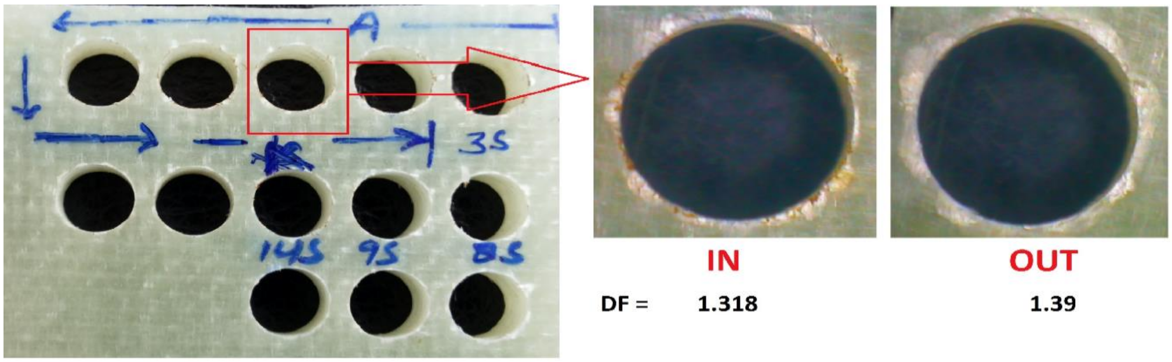
Experiment Run No: 8



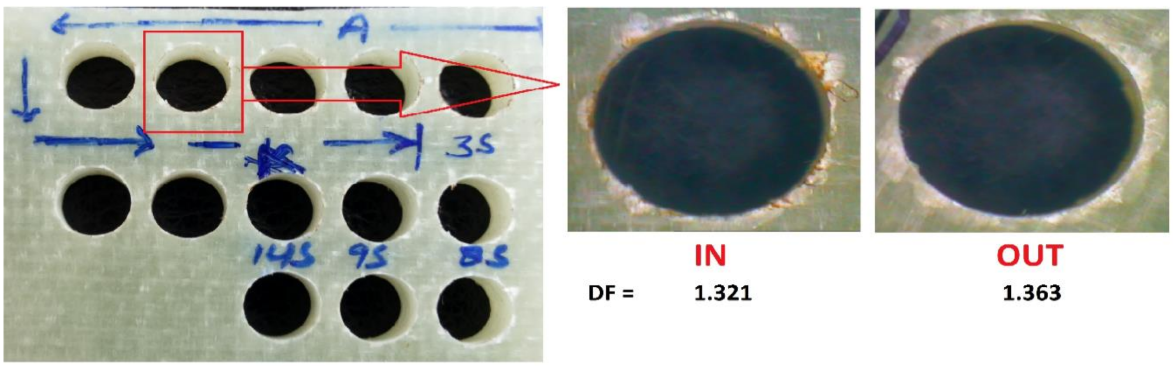
Experiment Run No: 9



Experiment Run No: 10



Experiment Run No: 11



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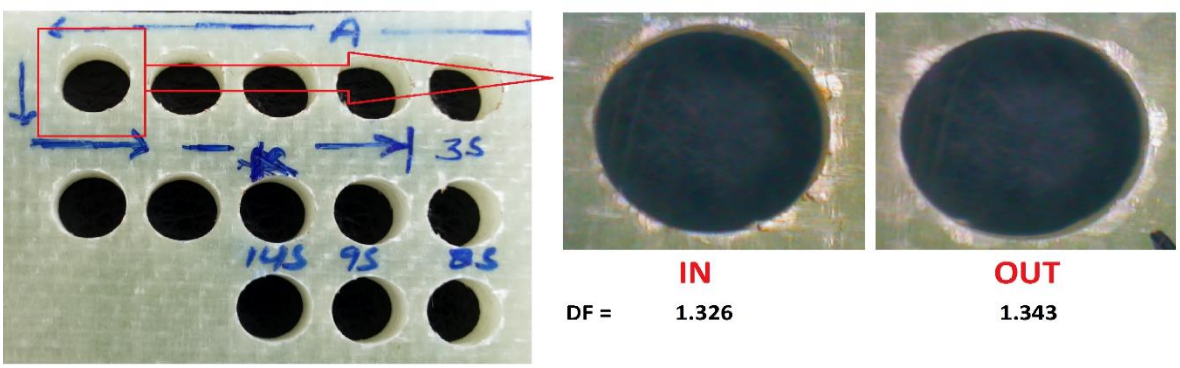
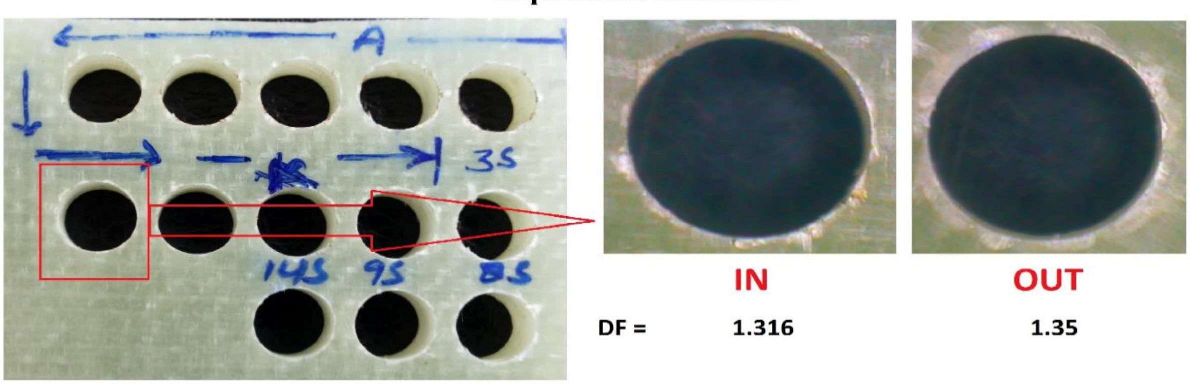


Experiment Run No: 13



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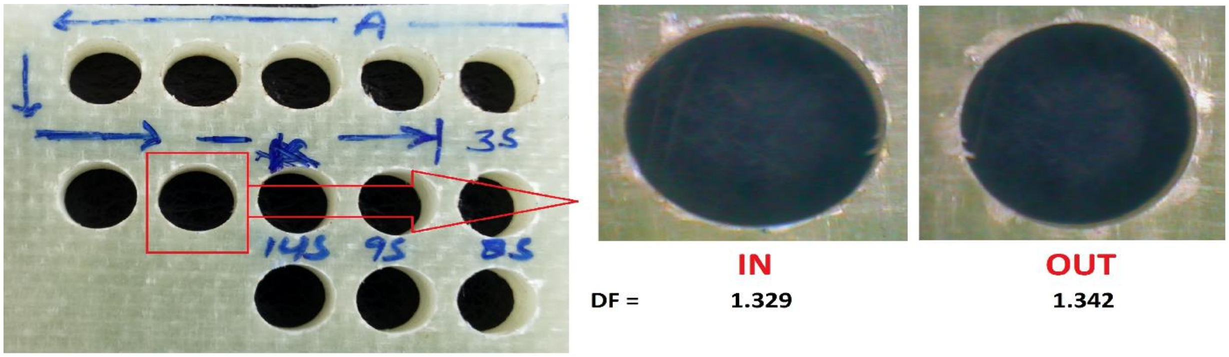
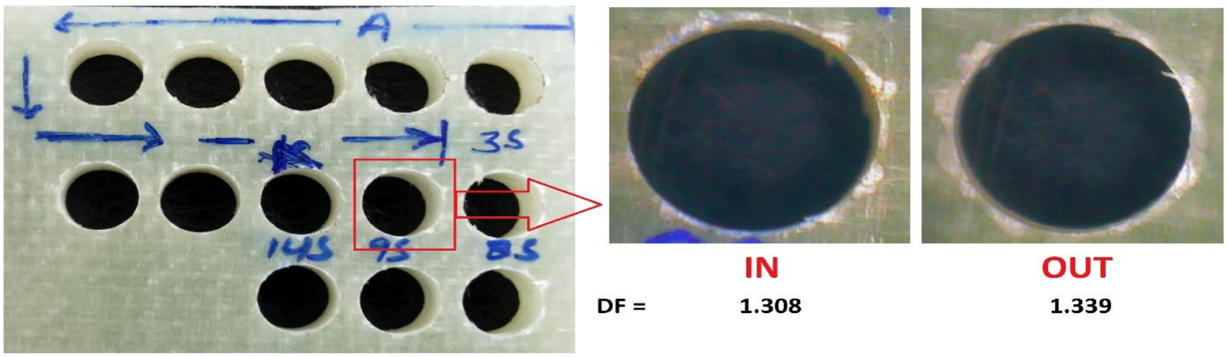


Experiment Run No: 15



Experiment Run No: 16

Fig 5.3: Delamination observed through an Optical microscope of 6mm and 8 mm drilled holes.

Table 5.2: Performance Characteristics observed during experiment.

Sl. No.	Thrust [kN]	Torque [kN-mm]	Ra (μm)	Fd(in)	Fd(out)
1.	0.092	0.48	7.78	1.4435	1.4766
2.	0.109	0.43	6.229	1.3347	1.4082
3.	0.085	0.32	5.24	1.3232	1.4369
4.	0.101	0.83	8.774	1.4161	1.419
5.	0.098	0.76	8.134	1.4137	1.4559
6.	0.097	0.9	6.248	1.4598	1.5435
7.	0.076	0.77	6.183	1.3694	1.4101
8.	0.078	1.04	7.383	1.3937	1.4216
9.	0.229	0.76	6.224	1.3098	1.3705
10.	0.248	0.79	8.443	1.3141	1.3737
11.	0.185	0.48	6.533	1.3184	1.3901
12.	0.21	0.81	7.285	1.3205	1.3626
13.	0.135	0.41	5.772	1.3258	1.3433
14.	0.161	0.5	7.86	1.3159	1.3502
15.	0.124	0.42	6.56	1.3291	1.3422
16.	0.136	0.62	5.685	1.3081	1.3386

5.3 Calculations

Now, the utility attribute of the methodology was calculated using Utility concept. The individual utility index was then formed in following manner;

Table 5.3: Calculation of individual utility factors.

Sl. No.	Utility-Thrust	Utility-Torque	Utility-Ra	Utility-Fd(in)	Utility-Fd(out)
1.	7.54612	5.903941	2.099299	0.921027	2.79996
2.	6.255818	6.743888	5.981309	7.348784	5.79704
3.	0.606547	2.395033	5.995329	8.893471	7.5118
4.	0	2.099416	0.671417	8.624631	7.36443
5.	8.148334	9	9	8.05858	4.52214
6.	6.835889	1.722262	0	2.492947	5.31426
7.	2.230208	5.903941	5.149344	8.35667	6.6145
8.	1.265661	1.908511	3.247083	8.226122	7.8771
9.	4.627891	7.107567	7.311692	7.897566	8.77852
10.	3.287592	5.592231	1.920681	8.512355	8.45477
11.	7.065345	2.395033	1.322401	2.632079	3.69207
12.	7.143395	1.103997	5.928133	0	0
13.	5.274667	6.923562	5.077334	7.693657	8.83029
14.	4.571731	3.949679	7.576862	9	9
15.	9	2.295217	6.110724	5.24354	5.71184
16.	8.802333	0	3.013775	3.800784	5.19859

With the help of the data accumulated as individual utility index, overall utility was calculated. Thereafter by the implementation of Taguchi methodology the S-N ratio for each individual utility factor was calculated.

Table 5.4: Calculation of overall utility and predicted S/N ratio.

Sl. No.	N (RPM)	F(mm/min)	D (mm)	Overall utility	S/N ratio	P- S/N ratio
1.	800	200	6	3.85407	11.71839	18.08446
2.	800	250	6	6.425368	16.15796	
3.	800	300	8	5.080436	14.11802	
4.	800	350	8	3.751978	11.48521	
5.	1000	200	6	7.745811	17.78134	
6.	1000	250	6	3.273072	10.29911	
7.	1000	300	8	5.650932	15.0424	
8.	1000	350	8	4.504895	13.07369	
9.	1200	200	8	7.144648	17.07962	
10.	1200	250	8	5.553526	14.89138	
11.	1200	300	6	3.421385	10.68404	
12.	1200	350	6	2.835105	9.051382	
13.	1400	200	8	6.759901	16.59881	
14.	1400	250	8	6.819654	16.67525	
15.	1400	300	6	5.672264	15.07513	
16.	1400	350	6	4.163096	12.38833	

After attaining the S-N ratio values for each individual, the values were processed in MINITAB and following graph was obtained.

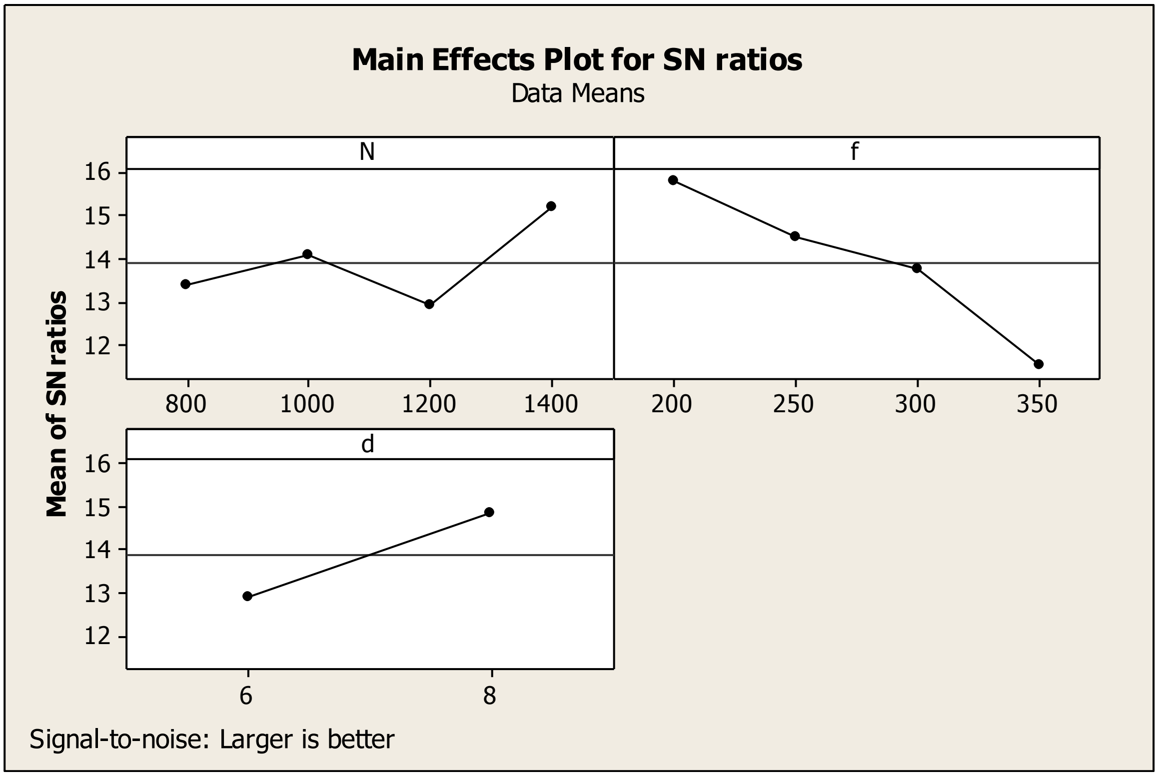


Fig.5.4: Plot of S-N ration, basis experimental observation.

As we know, for the experimentation Taguchi methodology and Utility concept was integrated. Henceforth to find the optimal value Higher-is-better criteria is implemented. The optimal combination obtained from the S/N ratio plot (Fig. 5.4) is shown below in Table 5.5.

Table 5.5: Optimal combinations of process parameters

Factor	Spindle Speed (N)	Feed (f)	Dia of Drill (d)
Level	1400 rpm.	200 mm/min.	8 mm.

Chapter 6: Conclusions and Future Scope

6.1 Conclusions

Taguchi method refers to optimize a single-response problem, so utility combined with Taguchi method) is used to optimize control parameters. In the present study based on the data analysis and experimental results the following conclusions can be drawn.

Utility methodology is used to convert the multi responses (thrust, torque, delamination factor (both at entry and exit) and surface roughness) into a single response i.e. overall utility index. Finally, Taguchi has been implemented on overall utility index to obtain the optimal parametric combination.

Now the optimal combinations of process parameters obtained from S/N ratio plot are N=1400 rpm, Feed=200 mm/min, Drill Diameter=8 mm. It has been observed that predicted S/N ratio value for this combination is 18.08446, which is higher among the all computed S/N ratios. Hence it has been observed from the results that quality of the product can be improved using this methodology.

6.2 Future Scope

The present work can be extended for further quality improvement like other machining parameters and material parameters can also be taken into account for experimental analysis.

1. To study machining behavior of GFRP composite using coated (PVD and CVD) and uncoated tools.
2. Response surface methodology and evolutionary techniques such as genetic algorithm, harmony search method may be incorporated in future to determine optimal parameter setting.
3. Apart from the drilling, other convention machining operations such as turning, milling etc. will be carried out to study the machinability aspects of GFRP composites.

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